Please make note of the following information:

- SAM website – www.nrel.gov/analysis/sam/
- SAM on Google Groups – groups.google.com/group/sam-user-group
- SAM support email – solar.advisor.support@nrel.gov

Introduction to SAM 2010.11.9

Paul Gilman

Webinar

February 7, 2010

Welcome

- Paul Gilman
  – Provide user support
  – Write documentation
  – Involved with SAM project since 2005
  – solar.advisor.support@nrel.gov

Logistics

- All participants will be muted
- Questions will not be answered during session.
  - Any questions will be posted an answered on Google Groups
  - Post any follow-up questions or discussion on Google Groups
  - groups.google.com/group/sam-user-group
- Will post talking points and recording on SAM website

Introduction

- Overview of software: Will cover enough information to get you started
- Technology focus will be PV
  - PV topics will familiarize CSP modelers with interface
  - CSP topics will introduce optimization and graphing techniques for PV modelers
  - Brief introduction to non-solar technologies
- Three hours is a long time, so feel free to tune in and out as needed
- Will present topics in order of agenda in announcement

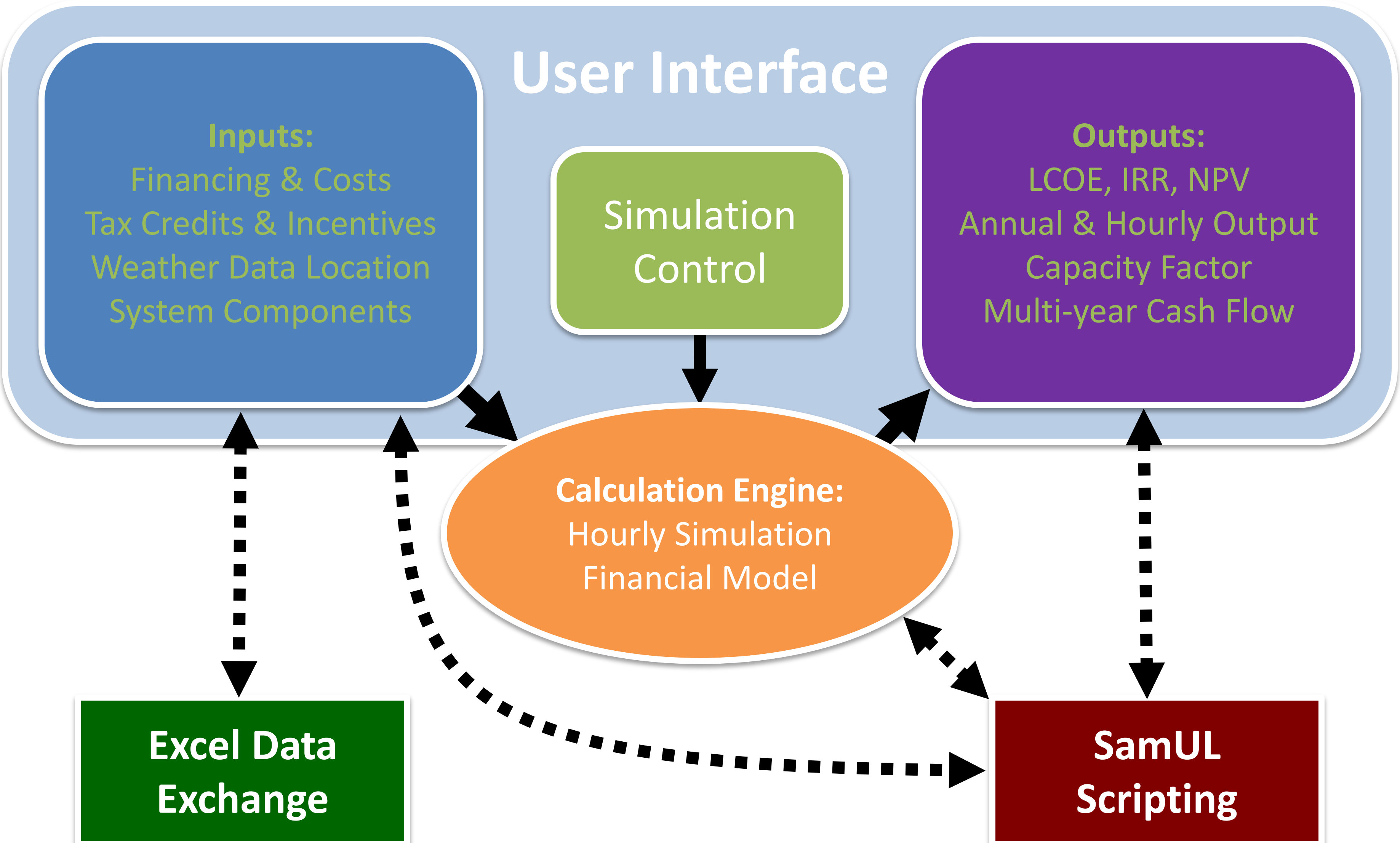
Agenda

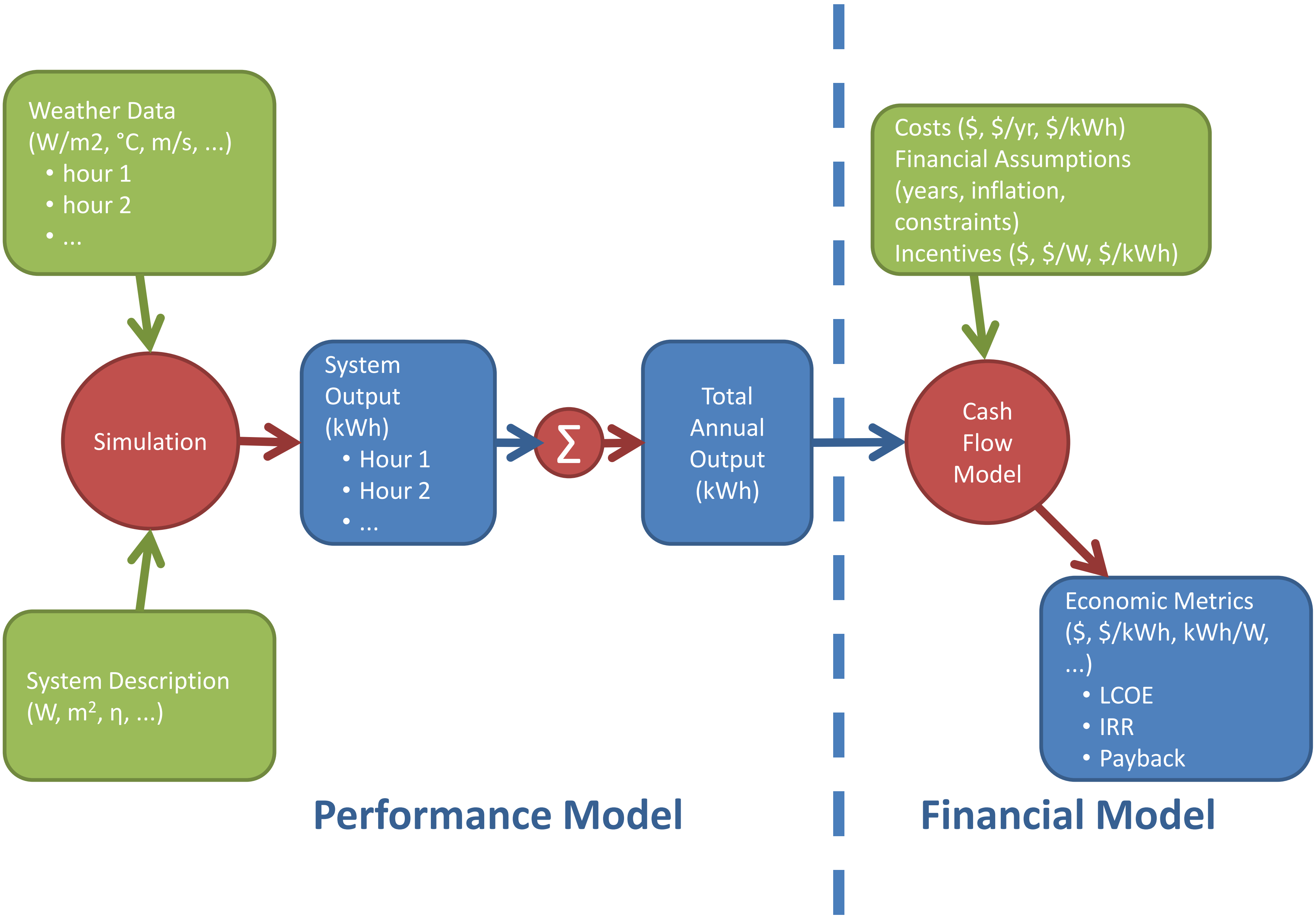
- Overview of user interface
- Financial structures for residential, commercial and utility projects
- Solar, wind, and geothermal power systems
- Hourly simulations
- Economic and performance metrics
- Graphs and tables of outputs
- Input requirements

What is SAM?

The System Advisor Model (SAM) is a free computer program that **calculates a renewable energy system's hourly energy output** over a single year, and **calculates the cost of energy** for a renewable energy project over the life of the project.

Program Structure




Weather Data
(W/m2, °C, m/s, ...)
• hour 1
• hour 2
• ...
Simulation
System Description
(W, m², η, ...)
System Output (kWh)
• Hour 1
• Hour 2
• ...
Σ
Total Annual Output (kWh)
Costs ($, $/yr, $/kWh)
Financial Assumptions
(years, inflation, constraints)
Incentives ($, $/W, $/kWh)
Cash Flow Model
Economic Metrics
($, $/kWh, kWh/W, ...)
• LCOE
• IRR
• Payback
Performance Model
Financial Model

Introduction to SAM 2010.11.9

OVERVIEW OF USER INTERFACE

SAM

- What is it?
  - System Advisor Model
  - Calculates a power system's hourly output over the period of one year
  - Calculates a power project's annual costs over a specified analysis period
- Inputs
  - Weather data
  - Characteristics of system
  - Installation and operating costs
  - Financial structure
  - Incentives
- Outputs
  - Hourly power output with monthly and annual averages
  - Net annual cash flow
  - Summary metrics: LCOE, payback period, total annual output, capacity factor
  - Intermediate values available for more detailed analysis

Welcome Page

- Appears when you first start SAM
- Choose how to open the file
  - Sample file
  - New file
  - Recent file
- If you have an old file from SAM 3.0: File $\rightarrow$ Import SCIF

Files and Cases

- A file contains one or more cases
- Use tabs to display cases
- Cases are like worksheets in an Excel workbook
- Each case contains a complete set of inputs and results
- Use cases to compare different analysis scenarios
  - Technologies
  - Financing structures

Navigation Menu and Input Pages

- Click navigation buttons to display input pages
  – Button labels show summary values
- Input pages display input variables
  – All input variables have default values
  – Default values are samples, not official values from NREL or DOE

Running Simulations

- Review and modify inputs
- Click Run to start simulations and display results
- Click Switch to Graphs and Results Viewer to see results without running simulations
- Click Configure Simulations for advanced analyses

Viewing Results

- Metrics table
- Graphs and charts
  - Display and organize graphs
  - Customize graphs
- Base Case Cashflow
- Tabular Data Browser
  - Build custom tables
  - Run simulations to show hourly data
- Case Summary Spreadsheet (Windows Only)
- Hourly data viewer (Windows Only)

Exporting Graphs and Data

- Metrics table
  - Shortcut menu commands (right-click)
- Graphs
  - Copy graph data and Show graph data buttons
  - Shortcut menu commands (right-click)
- Base Case Cashflow and Tabular Data Browser
  - Copy to clipboard, Save as CSV, and Send to Excel buttons

Notes and Help

- Use Notes to store text about a page
  - Add notes to input pages
  - Clear notes by deleting text in notes box
- Help
  - Press F1 in Windows or command-? in Mac OS to show help topic for a page in SAM
  - Use contents and search to find information in Help

Introduction to SAM 2010.11.9

FINANCIAL STRUCTURES FOR RESIDENTIAL, COMMERCIAL AND UTILITY PROJECTS

Example 1: Commercial PV System

- Inputs
  - New Project
  - Save as “Financing Examples”
  - Photovoltaics, PVWatts System Model, Commercial Market, Standard Loan
  - Name “Commercial PV Example - Default”
- Results
  - Annual Energy, compare to current usage
  - LCOE Nominal, compare to electricity rates
  - Payback period

Example 2: Commercial PV System in Portland, Oregon

- Inputs
  - Case, Duplicate
  - Case, Rename, “Commercial PV Example – Portland”
  - PVWatts Solar Array, 16 kW
- Results
  - Annual output reduced by about 35%
  - Payback period doubles
  - NPV negative

Can I improve financing to make project feasible?

- Compare cash flow graphs
  - Look at debt payments in years 6-15
  - Cash flow table shows annual revenue – sufficient to cover higher debt payments
- Try increasing debt fraction from 60% to:
  - 80%: NPV is positive
  - 90%: LCOE on par with Phoenix
  - Payback does not change because capital cost and revenue do not change
- Try reducing module cost from $1.92 to $0.50
  - Payback drops to 10 years

Example 3: Utility CSP Parabolic Trough System

- Inputs
  - Case, Create
  - Concentrating Solar Power, Physical Trough System, Independent Power Producer
  - Review system description
  - Run
- Results
  - PPA Price
  - IRR
  - What price does the project need to earn to cover installation and operating costs?

Utility Financing Inputs

- Inputs not in commercial and residential financing:
  - Construction period
  - PPA escalation rate – Often negotiated as part of a power purchase agreement
  - Debt fraction – Determines debt-equity ratio, often a controllable parameter in financial negotiations
  - Constraining assumptions – Rate of return and debt service coverage requirements for financial partner
  - Optimization – Allow SAM to calculate debt fraction and escalation rate that result in lowest PPA price

Example 4: Compare to similar-sized PV system

- Inputs
  - Case, Create
  - Photovoltaics, Component-based Models, Utility Market, Independent Power Producer
  - Climate, CA Blythe
  - Array, Desired Array Size, 100,000 kWdc
- Results
  - Use tabs to compare results and inputs
  - For this example, results are not meaningful because assumptions are based on default values – need to refine inputs

Example 5: Calculate IRR instead of PPA price

- Inputs
  - Case, Duplicate
  - Case, Rename, “Utility PV Bid Price”
  - Select Technology and Market, Utility Market, First Year Bid Price
  - Financing, Bid Price, $0.12/kWh; Escalation, 0.6
- Results
  - 20% IRR
  - Compare to IPP example with 26% IRR and $0.14/kWh PPA price

For California Projects

- Payment Allocation Factors allow time-variable pricing for PPA projects
- Specify factors and time-of-delivery periods
  - PV: Energy Payment Dispatch page
  - CSP: Payment Allocation Factors on Thermal Storage page

Commercial Financing Options

- Apply to all financing options:
  - General
  - Taxes and Insurance
  - Salvage Value
- Loan parameters
  - Standard, mortgage-style debt
  - Debt fraction specifies percentage of total installed costs that project borrows
- Depreciation
  - Treated as positive cash flow

Resources for more Information

- Financial spreadsheets under Help menu
- Help topics:
  - Input page reference, Financing
  - Results, Metrics Table
  - Results, Base Case Cashflow
  - References, Project Economics and Financing

System Costs

- Categories are similar for all technologies
- Capital costs
  - SAM uses total installed costs
  - Categories are for your bookkeeping
- Operating Costs
  - Specify in $/yr, $/kW-yr, or $/kWh-yr
  - Annual schedules
- Default values are estimates: Take ownership of your assumptions
  - See Help, SolarBuzz, SAM website

Summary

- Residential and commercial financing: LCOE represents cost of installing and operating project over the analysis period expressed in cents/kWh
- Utility projects: LCOE represents PPA price over life of project expressed in cents/kWh
- Use cash flow table to examine details of financial analysis
- Use cases to compare different analysis scenarios
- Take ownership of your assumptions – do not depend on default input values

Introduction to SAM 2010.11.9

SOLAR, WIND AND GEOTHERMAL POWER SYSTEMS

Photovoltaic Systems

- Component-based models
  - Module and inverter modeled separately
  - Build system on Array page
  - Array shading and self-shading
- PVWatts System Model
  - Entire system modeled as a single DC-to-AC derate factor with temperature correction
  - Array shading

Example 5: 150 kW PV System

- Inputs
  - File, New Project
  - Photovoltaics, Component-based Models, No Financials, “15 kW PV System”
  - Module, Sandia, AstroPower APX-140
  - Inverter, Sandia, SMA SB5000US 240V
  - Array, Desired Array Size 15 kWdc; Fixed 10 degree tilt
- Results
  - Simulation warning
- Refine inputs
  - Module, AstroPower AP-75
  - Array, verify sizes
- Results
  - Annual output
  - Monthly output
  - Hourly output

Choosing a module model

- Component-based or PVWatts
  - For quick analyses or for large numbers of runs, use PVWatts
  - When you need more detailed outputs, use component-based
- Sandia or CEC?
  - Look for a module first in Sandia, then CEC
  - Avoid modeling thin-film modules with CEC
  - If your module is in neither database, look for a similar module, or use simple efficiency
- Use simple efficiency for parametric studies on efficiency or temperature coefficient
- Concentrating PV for CPV modules
- when your module is in neither database (or use a similar module from one of the databs

Example 6: 150 kW PV system in simple efficiency model

- Inputs
  - Case Duplicate
  - Case Rename, “15 kW PV System Simple.”
  - Module, Simple Efficiency Module; Efficiency, 10.83; Temp Coeff, -0.542; Area, 0.633
- Results
  - Annual output increases by about 8%
  - Simple model with constant efficiency does not represent dependence of module conversion efficiency on radiation level

Choosing an Inverter Model

- Sandia Model when you have a particular inverter in mind
- Single-point efficiency for generic inverter, or for parametric studies on efficiency and nameplate capacity

Tips

- Update your version of SAM to put Sandia database in alphabetical order

CSP Systems

- Parabolic trough
- Power tower
- Dish-Stirling
- Generic when you have a table optical efficiencies for a range of sun positions

Overview of Trough Sample File

- Physical or empirical?
  - Use physical for more accurate modeling: Equations based on physical properties of system components
  - Use empirical for faster modeling: Equations based on empirical measurements of SEGS plants
- Climate and Financing input pages are the same as PV
- Default costs based on NREL-sponsored study
  - See Excel Exchange

Solar Multiple

- A way to specify the solar field size as a function of the power block capacity
- SM = 1: At reference radiation, solar field output equals power block design input
- Optimal value depends on location (resource) and cost of solar field components

Parabolic Trough: Basic Design Steps

- Choose a location
- Choose appropriate reference DNI
- Specify power block capacity
- Optimize solar multiple for lowest LCOE
- Lessons for non trough modelers
  - Running an optimization using parametric analysis
  - Creating a custom graph

Example 7: Trough Solar Field Optimization

- Inputs
  - New project, Concentrating Solar Power, Physical Trough System, Utility Market, Independent Power Producer
  - Case name “optimize solar field trough”
  - Climate, NV Ely
  - Thermal Storage, Hours of storage, 0
  - Power Cycle, Design gross output, 55 MWe
  - Run, Results, View Hourly Time Series, Boxplot, Collector_DNI-x-CosTh, Ann Max
  - Solar Field, Irradiation at Design, 980
  - Parametrics, Solar Field, Solar Multiple, 1.25, 2.5, 0.25
- Results
  - LCOE vs Solar multiple

Solar Multiple Optimization with Storage

- Example in sample file
  - Same steps as shown without storage
  - Add hours of TES as parametric variable
  - Plot LCOE vs SM for different TES capacity values
- See instructions in Help

Other technologies

- Solar
  - Power tower
  - Dish-Stirling
  - Generic solar: When you have a table of optical conversion efficiencies for different sun angles
  - Solar water heating
- Non-solar
  - Small-scale wind
  - “Wind Turbine Design”
  - Geothermal

Introduction to SAM 2010.11.9

HOURLY SIMULATIONS AND FINANCIAL MODEL

Simulation

- SAM Uses TRNSYS engine
- View hourly weather data input file
  - DView from Climate page
  - Weather file in weather folder
- View hourly results in different formats
  - Tabular data browser
  - DView
  - Case summary spreadsheet
  - TRNSYS output file

Financial Model

- SAM uses total annual output from simulations as first year output for cash flow calculations
  - First row in cash flow table
  - Output in subsequent years depends on degradation factor on Annual Performance page
- Costs are first-year costs
  - First column in cash flow table
  - SAM calculates out-year costs using inflation rate and any escalation rates

Introduction to SAM 2010.11.9

ECONOMIC AND PERFORMANCE METRICS

Metrics Table

- Annual energy production
- Capacity factor
- LCOE (levelized cost of energy)
- Internal rate of return (IRR)
- Minimum DSCR (debt-service coverage ratio)
- Net present value (NPV)
- PPA Price (power price under a power purchase agreement)

Introduction to SAM 2010.11.9

GRAPHS AND TABLES OF OUTPUTS

Graphs

- Built-in graphs
  - Displaying graphs
  - Exporting graphs
  - Showing graph data
- Creating graphs
  - Modify a graph
  - Create a new graph
- Hourly Data Viewer (DView)

Tables

- On Results page
  - Base case cash flow table
  - Tabular data browser
- In Excel
  - Case summary spreadsheet
  - Export to Excel options

Sliders

- Dynamically change graphs while viewing them
- Only work with financial variables due to calculation speed

Introduction to SAM 2010.11.9

INPUT REQUIREMENTS

Weather Data: Climate Page

- Financial analysis over long periods requires weather data that represents “typical” weather at a site
  - TMY2
  - TMY3
  - Perez: Solar Prospector or Location Lookup
- Typical year data for non-U.S. locations is limited
  - EnergyPlus
  - Meteonorm
- TMY3 Creator allows you to build your own weather file

System Characteristics

- Mathematical models represent physical characteristics of components
  - Equation coefficients describe properties of different types of equipment
- Libraries to select coefficient sets where possible
  - PV modules, inverters
  - HTF, field components for CSP systems
- Default values to help guide you in choosing input values

Project Costs and Financial Assumptions

- System costs
  - Installation costs
  - Operating costs
- Financial assumptions
  - Debt parameters
  - Returns requirements for utility-scale projects
  - Taxes
  - Incentives
  - Tax credits
- Very project- and location-specific
  - Default values provide rough estimates

Summary of Tomorrow’s Session

- Comparing cases
- Optimization
- Uncertainty analysis
- Scripting with SamUL
- Excel Exchange
- Generating code to call SAM from Python, C, MATLAB, and VBA programs

Thank You

- Check SAM website for recording and talking points
- Post questions or comments on Google Groups